Optimal Signal Processing for Next-Generation Communication Systems

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Declaration

This dissertation is the result of a research candidature conducted with another University as part of a collaborative Doctoral degree. I certify that the work in this dissertation has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements.

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Abstract

In order to meet consumers' exponentially growing demand, the next-generation wireless communication systems are aimed at achieving high data rate, low latency, large device density, and superior energy efficiency (EE). In this dissertation, we address problems in different scenarios to ensure superior performance of next-generation wireless communication systems.

We first consider the pilot sequence design for orthogonal frequency-division multiplexing (OFDM) systems in a high mobility environment. The design of pilot sequence to minimize the mean squared error (MSE) of the channel estimate is proposed under a linear minimum mean squared error (LMMSE) estimator for average path gains. Due to the existence of interferences of pilot and data subcarriers, the MSE of the LMMSE estimator is a nonconvex function. Then, the MSE of the LMMSE estimator is transformed to a concave quadratic function and we develop a path-following optimization procedure, which improves the MSE in every iteration and it quickly converges at least to its local optimal solution. The developed path-following procedure can also be adapted to design pilot sequences for the least-square (LS) and maximum-likelihood (ML) estimators.

The second part of research is devoted to the optimal design of training sequences for channel estimation in large-scale multiple-input multiple-output (MIMO) OFDM systems. Under the criterion of minimizing the MSE of the channel estimate, the optimal design of training sequences for such systems poses a truly large-scale optimization problem, to which existing optimization solvers are not applicable. We develop a fast convex programming (FCP) procedure to find its global optimal solution. In each iteration of the proposed FCP procedure, a solution is found in a scalable and closed form. The singularity and ill-conditionedness of the channel correlation matrices are

also exploited to improve the computation efficiency. Furthermore, we also examine the design of reduced-length training sequences and develop a successive quadratic programming (SQP) procedure to find the solutions.

Thirdly, we consider the joint design of user power allocation and relay beamforming in relaying communications, in which multiple pairs of single-antenna users exchange information with each other via multiple-antenna relays in two time slots. The aim is to maximize the system's EE subject to quality-of-service (QoS) constraints in terms of exchange throughput requirements. The QoS constraints are nonconvex with many nonlinear cross-terms, so finding a feasible point is already computationally challenging. The sum throughput appears in the numerator while the total consumption power appears in the denominator of the EE objective function. The former is a nonconcave function and the latter is a nonconvex function, making fractional programming useless for EE optimization. Nevertheless, efficient iterations of low complexity to obtain its optimized solutions are developed.

Finally, we consider MIMO multicell networks, where the base stations (BSs) are full-duplex transceivers, while uplink users and downlink users are equipped with multiple antennas and operate in a half-duplex mode. The problem of interest is to design linear precoders for BSs and users to optimize the network's energy efficiency. Given that the EE objective is not a ratio of concave and convex functions, the commonly-used Dinkelbach-type algorithms are not applicable. We develop a low-complexity path-following algorithm that only invokes one simple convex quadratic program at each iteration, which converges at least to the local optimum.

Publications

The contents of this thesis are based on the following papers that have been published, accepted, or submitted to peer-reviewed journals and conferences.

Journal Papers:

1. Zhichao Sheng, Hoang Duong Tuan, Ha H. Nguyen, and Yong Fang, "Pilot optimization for estimation of high-mobility OFDM channels," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 10, pp. 8795-8806, Oct. 2017.

2. Zhichao Sheng, Hoang Duong Tuan, Ha H. Nguyen, and Mérouane Debbah, "Optimal training sequences for large-scale MIMO-OFDM systems," *IEEE Transactions on Signal Processing*, vol. 65, no. 13, pp. 3329-3343, July 2017.

3. Zhichao Sheng, Hoang Duong Tuan, Trung Q. Duong, and H. Vincent Poor, "Joint power allocation and beamforming for energy-efficient two-way multi-relay communications," *IEEE Transactions on Wireless Communications*, vol. 16, no. 10, pp. 6660-6671, Oct. 2017.

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5. Zhichao Sheng, Hoang Duong Tuan, Ali Arshad Nasir, Trung Q. Duong, and H. Vincent Poor, "Power allocation for energy efficiency and secrecy of wireless interference networks," *IEEE Transactions on Wireless Communications*, vol. 17, no. 6, pp. 3737-3751, June 2018.

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Conference Papers:

1. Zhichao Sheng, Hoang Duong Tuan, Yong Fang, Ho Huu Minh Tam, and Yanzan Sun, "Data rate maximization based power allocation for OFDM system in a high-speed train environment," in *Proc. 2015 IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, pp. 265-269, December 2015.

2. Zhichao Sheng, Hoang Duong Tuan, and Yong Fang, "Power allocation for OFDM system in a high-speed train environment," in *Proc. 2015 IEEE 26th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, pp. 650-655, September 2015.

3. Zhichao Sheng, Hoang Duong Tuan, Ha Hoang Kha, and Yong Fang, "Effectively inserted training for channel state estimation of spatially correlated MIMO-OFDM," in *Proc. 2016 IEEE Sixth International Conference on Communications and Electronics (ICCE)*, pp. 89-93, July 2016.

4. Zhichao Sheng, Hoang Duong Tuan, Ali Arshad Nasir, and H. Vincent Poor, "Secrecy throughput of wireless interference networks with uncertain channel state information," in *Proc. 2017 IEEE Global Communications Conference: Workshops: 5th IEEE GLOBECOM Workshop on Trusted Communications with Physical Layer Security*, December 2017.

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